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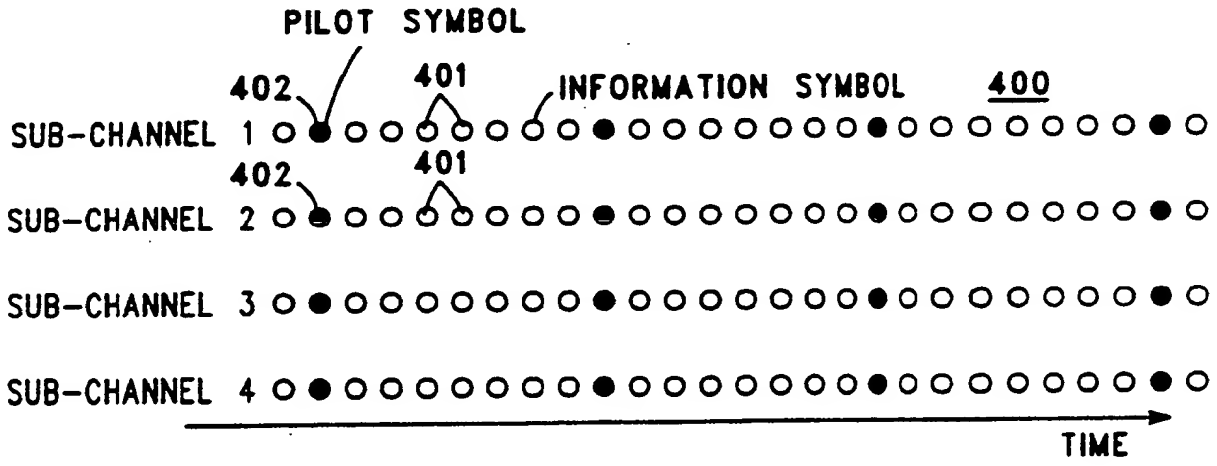
(54) Title: COMMUNICATION SIGNAL HAVING A TIME DOMAIN PILOT COMPONENT



(57) Abstract

A quad 16 QAM transmission and reception methodology wherein a time domain pilot reference is advantageously associated therewith. There may be one or more such pilot references (402) for each packet of multiple 16 QAM pulses. Depending upon the embodiment, each 16 QAM pulse can include a time domain pilot reference, or an estimated pilot reference for that pulse can be determined either by reference to pilot references in other pulses sharing the same packet, or by reference to pilot references for other previously received 16 QAM pulses corresponding to that same pulse.

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COMMUNICATION SIGNAL HAVING A TIME DOMAIN PILOT COMPONENT

Technical Field

This invention relates generally to communication methodology, and more particularly to communication signals having information components that require the presence of a pilot component in order to facilitate recovery of the information components.

Background of the Invention

Various communication systems are known in the art. Pursuant to many such systems, an information signal is modulated on to a carrier signal and transmitted from a first location to a second location. At the second location, the information signal is demodulated and recovered.

Typically, the communication path used by such a system has various limitations, such as bandwidth. As a result, there are upper practical limitations that restrict the quantity of information that can be supported by the communication path over a given period of time. Various modulation schemes have been proposed that effectively increase the information handling capacity of the communication path as measured against other modulation techniques. For example, a 16 point

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quadrature amplitude modulation (QAM) approach provides a constellation of modulation values (distinguished from one another by phase and amplitude) wherein each constellation point represents a plurality of information bits.

Such QAM signals are typically transmitted in conjunction with a pilot component. For example, the information components of the QAM signal can be broadcast in conjunction with one or more pilot tones that are offset in frequency from the information content itself. These pilot components can be utilized to support synchronization, and to otherwise support recovery of the information component in a variety of ways.

Unfortunately, such frequency offset pilot components themselves consume bandwidth, thereby reducing the amount of bandwidth available in a communication path to support the information components. If the information components are themselves parsed into frequency offset data packages, the problem increases as further spectrum must be utilized to support the multiplicity of pilot references that are typically required to allow recovery of the various information packets.

In partial response to this situation, the prior art has proposed the use of time domain pilot components. For example, the information components of a particular QAM transmission are combined with an inband predetermined pilot reference component that appears in a periodic manner. (Since the pilot component appears only from time to time, the component is referred to as

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existing in the time domain, as distinguished from the frequency domain pilot components discussed above.)

Though suitable for many applications, QAM transmissions that include time domain pilot components are not satisfactory in all applications. For example, in an RF communication environment, where communication units may be in motion with respect to one another, such prior art time domain pilot reference QAM methodologies may provide unacceptable performance. In particular, the land-mobile radio channel is characterized by multipath fading that causes the channel phase and amplitude to vary over time as the receiving or transmitting unit moves about. Such variations must be compensated or otherwise allowed for in order to provide proper reception. Typically, phase and frequency modulation schemes avoid the need for compensation since channel amplitude variations can be ignored and differential or discriminator reception techniques can automatically account for the channel phase variations. However, phase and frequency modulation are not very bandwidth efficient. While QAM techniques can introduce bandwidth efficiency by comparison, QAM requires more complicated channel compensation methods, such as those prior art techniques that use one or more pilot tones in association with the information content.

Another problem associated with the multipath nature of the radio channel is that of frequency-selective fading. This occurs whenever the delay difference between the various multipath components that arrive at the recievər become large enough relative to the signalling rate in the channel. When this happpens,

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the channel's frequency response will no longer appear to be flat in the band of interest, but will exhibit phase and amplitude variations with frequency, which in turn will vary with time as the transmitter or receiver moves about. This frequency-selective effect causes signal distortion that is present independent of the strength of the received signal. In data communication systems, this distortion manifests itself as an irreducible bit error rate, or error floor, that persists regardless of how strong the received signal becomes. In addition, the distortion effect worsens as the information capacity of the signal increases.

Accordingly, a need exists for a communication methodology that will provide efficient use of QAM (and the like) modulation techniques while simultaneously substantially avoiding spectral inefficiencies that may occur through use of certain prior art pilot component techniques and other multipath compensation techniques. This technique will preferably remain substantially robust in a varying multipath operating environment.

Summary of the Invention

These needs and others are substantially met through provision of the communication techniques disclosed herein. Pursuant to this invention, an original information signal is converted into a parallel plurality of processed information signal sample sequences. At least one of these sequences is then combined with a reference sequence containing at least one predetermined sample, which sample serves as a time domain pilot reference that a receiver utilizes to

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effectively recover a signal corresponding to the original information signal.

In one embodiment of the invention, the original information signal can be in the form of a serial data stream, and the conversion step operates upon preselected serial portions thereof.

In one embodiment of the invention, the conversion step further includes converting groups of bits that comprise the original information signal into corresponding multibit symbols. In a further embodiment, a predetermined plurality of these symbols constitutes a processed information signal sample sequence.

In one embodiment of the invention, the combining step includes combining the predetermined sample (which represents the time domain pilot reference) with at least two of the sample sequences. In another embodiment, all of the sequences are combined with a pilot tone reference in this manner.

In yet another embodiment, the time domain pilots can be provided in some, but not all, of a group of subchannels. To provide for channel compensation in the subchannels that do not have a pilot, the time domain pilots that are provided can be utilized to provide an estimation of a pilot for that subchannel. In effect, then, the occassionaly sent pilots can be utilized to interpolate both over time and over frequency to allow for channel compensation of the information signals.

Brief Description of the Drawings

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Fig. 1 comprises a block diagram depiction of a signal processor suitable for use in a transmitter in accordance with the invention;

Fig. 2 comprises a depiction of a 16 QAM symbol constellation;

Fig. 3 comprises a depiction of a symbol constellation wherein one of the symbols constitutes a predetermined pilot reference symbol;

Figs. 4a-c comprise timing diagrams representative of a series of symbol sequences as provided in various embodiments in accordance with the invention;

Fig. 5 comprises a spectral diagramatic representation of a plurality of sample sequences, each having been combined with a predetermined symbol, in accordance with the invention;

Figs. 6a-b comprise block diagrams depicting a receiver suitable for use in receiving a signal in accordance with the invention; and

Fig. 7 comprises a graph illustrating interpolated channel gains as determined in accordance with the invention.

Best Mode For Carrying Out The Invention

A signal processor for preparing a signal for transmission in accordance with the invention is generally depicted in Fig. 1 by the reference numeral 100. Though depicted in block diagram format for the convenience of explanation and understanding, it should be understood that the invention can be practiced in a variety of embodiments; in particular, a digital signal

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processor, such as from the Motorola DSP 56000 or DSP 96000 families, is readily programmable to accomplish the functions set forth below. Also, although described below in the context of a 16#QAM application, it should also be understood that the teachings herein are also applicable for use with other modulation schemes as well.

A processing unit (102) receives an original information signal (101). In this particular embodiment, this information signal constitutes a serial bit stream having an effective baud rate of 53.2 kilobits per second. This bit stream can represent, for example, true data, digitized voice, or other appropriate signals.

The processing unit (102) functions to convert groups of16 serial bits of the original information signal into four 16 QAM complex signal points (symbols). For example, Fig. 2 depicts a 16 QAM complex signal symbol constellation (200). Each symbol in the constellation represents a different combination of four serial bits. For example, a first one of these symbols (201) represents the bits "0001." A second symbol (202), on the other hand, represents the bits "0100," all in accordance with well understood prior art methodology.

For each serially received 16 original information bits, the processing unit (102) outputs, in parallel, on each of 4 signal paths (103-106), an appropriate representative multibit symbol as described above. A pilot insertion unit (107-110), located in each signal path (103-106), inserts a predetermined symbol following receipt of 7 serially received information symbols from the processing unit (102) pursuant to one embodiment of a communication methodology in

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accordance with the invention. For example, with reference to the constellation (200) depicted in Fig. 3, the symbol depicted by reference numeral 301 can, by way of example, serve as the predetermined symbol inserted by the pilot insertion unit (107-110). (Other symbols within the constellation could of course be used. Arbitrary signal points not within the constellation could also be used in an appropriate application. Furthermore, although a particular symbol is used to represent the pilot reference in this manner, this does not mean that this same symbol cannot serve as a multibit symbol for other symbol locations in the symbol stream. The preferred embodiment would in fact allow the predetermined symbol to perform this dual function. Lastly, it is not necessary that all of the pilot symbols be identical or spaced in time by a regular, uniform interval; it is only necessary that they be selected in a predetermined way.)

The resulting output from the pilot insertion units (107-110) comprises a symbol stream (in this embodiment having a symbol rate of 3.8 kilosymbols per second) that is as generally depicted in Fig. 4a by reference numeral 400. As depicted, a predetermined symbol (402) constituting a pilot reference serially appears following each 7 data symbols (401). This symbol stream forms a composite signal that includes one pilot reference symbol for every 7 data symbols. These composite signals are provided to pulse shaping filters (116-119) that appropriately shape the symbols for transmission.

Thereafter, each composite signal is mixed (121-124) with an appropriate injection signal (126-129) of

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the form $e^{(j2\Pi f_{offk}t)}$, wherein j is the square root of negative one, t is time, and f_{offk} comprises an offset frequency corresponding to the kth composite signal. All of the above parameters will be identical for each of the injection signals (126-129) with the exception of the frequency offset value. In this embodiment, the first injection signal (126) has an offset frequency value of minus 6.27 kHz. The second injection signal (127) has an offset frequency of minus 2.09 kHz. 2.09 kHz comprises the offset frequency for the third injection signal (128), and 6.27 kHz comprises the offset frequency for the fourth injection signal (129).

The filtered and offset composite signals are thereafter combined (131) to form a modulation signal. The real and imaginary parts of this complex modulation signal are separated (132, 133) and provided to a quadrature upconverter (134), following which the signal is amplified (135) and applied to an antenna (136) for transmission, the latter occurring in accordance with well-understood prior art methodology.

The resultant shaped, frequency offset, and combined 16 QAM symbol sequences are generally represented in Fig. 5 by reference numeral 500. As generally depicted in this spectral diagram, there are four effective sub-channels of symbol information (501), each being offset from the others in correlation to the offset frequencies referred to above. In this embodiment, each subchannel symbol also includes a time domain pilot reference sequence (figuratively represented by reference numeral 502) embedded therein. (It is not necessary that each 16 QAM subchannel symbol of this quad 16 QAM packet include an

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embedded time domain pilot reference. For example, only one of the QAM signals might include the pilot reference, as illustrated in Fig. 4b, with interpolation techniques being used during reception to provide an estimated pilot reference for use in recovering the remaining 16 QAM subchannels. In addition, or in the alternative, pilot sequences for the various subchannels might be staggered in time relative to each other, as depicted in Fig. 4c, to allow interpolation over time and frequency of estimated pilot references for use in recovering symbols for all subchannels. What is important is that a plurality of QAM signals be substantially simultaneously provided, in a manner frequency offset from one another, wherein at least one of the QAM signals includes a time domain pilot reference.)

A receiver suitable for use in recovering the above described signal has been set forth in Fig. 6a (600). Following appropriate reception of the transmitted signal as provided by, for example, an antenna (601), preselector (602), and quadrature downconverter (603), a composite signal centered substantially at zero frequency is provided to a bank of subchannel receivers (604a-d), for the purpose of recovering the original 16 QAM signals.

Operation of the subchannel recievers is further illustrated in Fig. 6b. The composite signal still comprising 4 parallel subchannels is mixed (606) with the appropriate injection signal of the form $e^{(-j2\Pi f_{offset}t)}$, in order to center the desired subchannel at approximately zero frequency (i.e., to remove the frequency offset introduced at the transmitter).

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A receiver pulse shaping filter (607) receives this mixed signal and appropriately shapes the received signal and filters out the other subchannel signals and noise to produce a single subchannel signal. A symbol sampler (608) then allows individual symbols to be sampled and provided to both of two processing paths (609 and 610). The first signal processing path (609) includes a pilot sampler (611) that selects the pilot symbols from the composite symbol sequence comprising data and pilot symbols. The pilot samples are then multiplied (612) by the reciprocal (613) of the original transmitted pilot symbol (which is known at the receiver by virtue of having been predetermined), to provide an estimate of the channel gain corresponding to the pilot sampling instant.

A pilot interpolation filter (614) then processes this recovered pilot sequence to obtain an estimate of the channel gain at the intervening data symbol instants.

Compensation of channel phase and amplitude distortion and recovery of the original data symbols are carried out as follows. Delay (616) provided in the second processing path (610) serves to time-align the estimated channel gains with the corresponding data symbols. The delayed data symbols are multiplied (617) by the complex conjugates (618) of the estimated channel gains. This operation corrects for channel phase but results in the symbol being scaled by the square of the channel amplitude. This is taken into account in the decision block (619) with appropriate input from a threshold adjustment multiplier (621) that itself utilizes nominal threshold information and a squared

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representation of the complex channel gain estimate (622).

The symbols received may have suffered degradation due to, for example, phase rotation and/or amplitude variations due to transmission and reception difficulties. By use of information regarding phase and/or amplitude discrepancies and/or effects that can be gleaned from the pilot interpolation filter, however, the symbols as output from the mixer are properly phase compensated. Having been thusly phase compensated, and given the appropriately adjusted decision thresholds as are also provided by the pilot filter, a decision can then be made as to which symbol has been received, and the detected symbol passed on for further processing as appropriate. Such processing would typically include, for example, combining detected symbols from different subchannel receivers, and conversion to a serial format.

Referring to Fig. 7, the function of the pilot interpolation filter (608) can be described in more detail. Complex channel gain relative to the overall transmission path can be seen as generally depicted by reference numeral 701. Pilot samples provide information regarding channel gain at the various time instants depicted by reference numeral 702. Based upon this sample information, interpolated channel gain estimates (703) can be made, which channel gain estimates are suitable for use in recovering data samples as described above.

This same methodology could of course be utilized to support transmission and reception of independent information signals that are to be sent in parallel with

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one another on a carrier. In effect, pursuant to this embodiment, the various subchannels described above would each carry information symbols that are independent of the other subchannels, but wherein the time domain pilot symbol(s) are interpolated over time (and frequency, if desired, as described above) to estimate channel conditions to thereby assist in the proper recovery of the information symbols from the various subchannels.

What is claimed is:

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Claims

1. A method of transmitting an original information signal, comprising the steps of:

A) converting a serial portion of the original information signal into a parallel plurality of processed information signal sample sequences;

B) combining at least one of the parallel plurality of processed information signal sample sequences with at least one predetermined sample;

wherein, each of the at least one predetermined samples serves as a time domain pilot reference.

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2. The method of claim 1 wherein the step of combining at least one of the parallel plurality of processed information signal sample sequences with at least one predetermined sample includes the step of combining each of the parallel plurality of processed information signal sample sequences with at least one predetermined sample.

3. The method of claim 2 wherein the step of combining each of the parallel plurality of processed information signal sample sequences with at least one predetermined sample produces a plurality of composite signals.

4. The method of claim 1, wherein the step of combining at least one of the parallel plurality of processed information signal sample sequences with at least one predetermined sample includes the step of combining at least two, but not all, of the parallel plurality of processed information signal sample sequences with at least one predetermined sample to provide at least two composite signals.

5. The method of claim 4 and further including the step of:

C) mixing each of:

the composite signals; and

those of the parallel plurality of processed information signal sample sequences that were not combined with at least one predetermined sample; with an offset signal to produce a plurality of offset signals.

6. A method of receiving a transmitted signal, wherein the transmitted signal comprises a signal formed from an original information signal by the steps of:

A) converting a serial portion of the original information signal into a parallel plurality of processed information signal sample sequences;

B) combining each of the parallel plurality of processed information signal sample sequences with at least one predetermined sample to form a composite signal;

wherein, each of the at least one predetermined samples serves as a time domain pilot reference;

the method comprising the steps of:

A) receiving the transmitted signal;

B) recovering the composite signals from the transmitted signal;

C) recovering, from each of the composite signals, the pilot reference associated therewith;

D) using the recovered pilot references to recover the original information signal.

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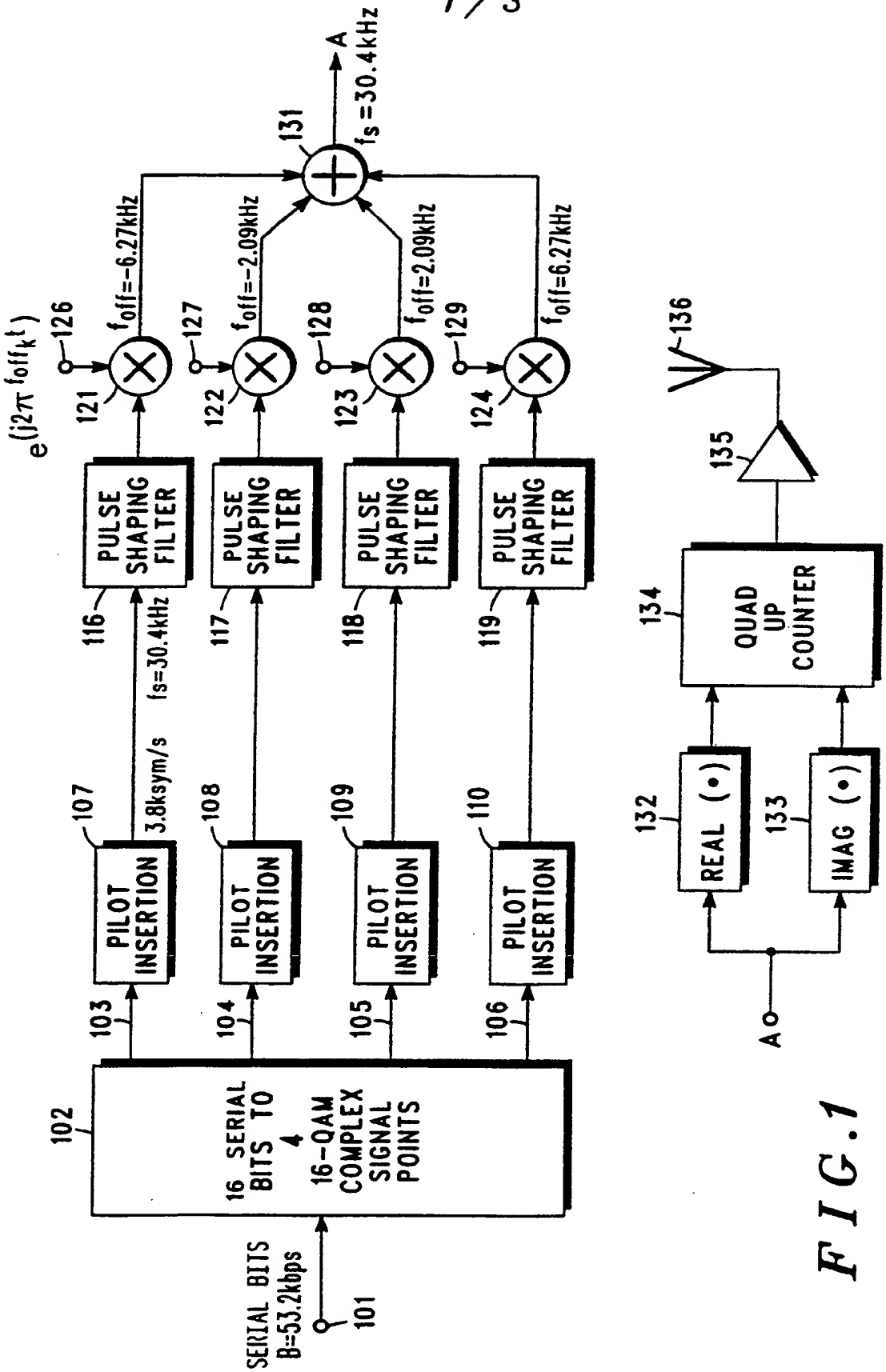

FIG. 1

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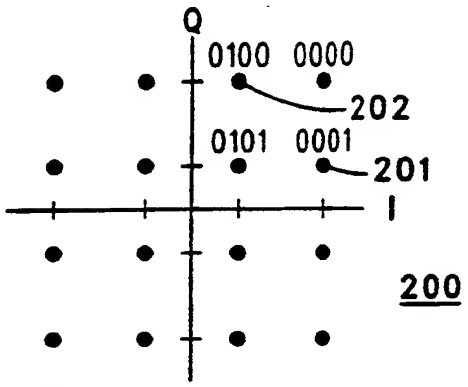

FIG. 2

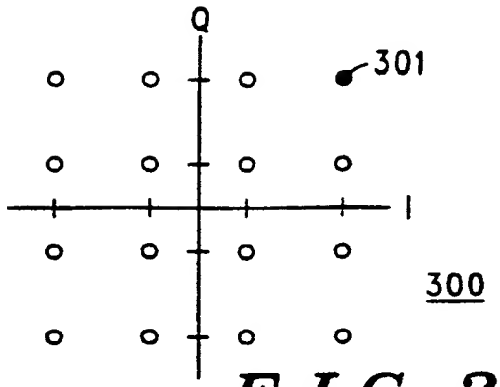

FIG. 3

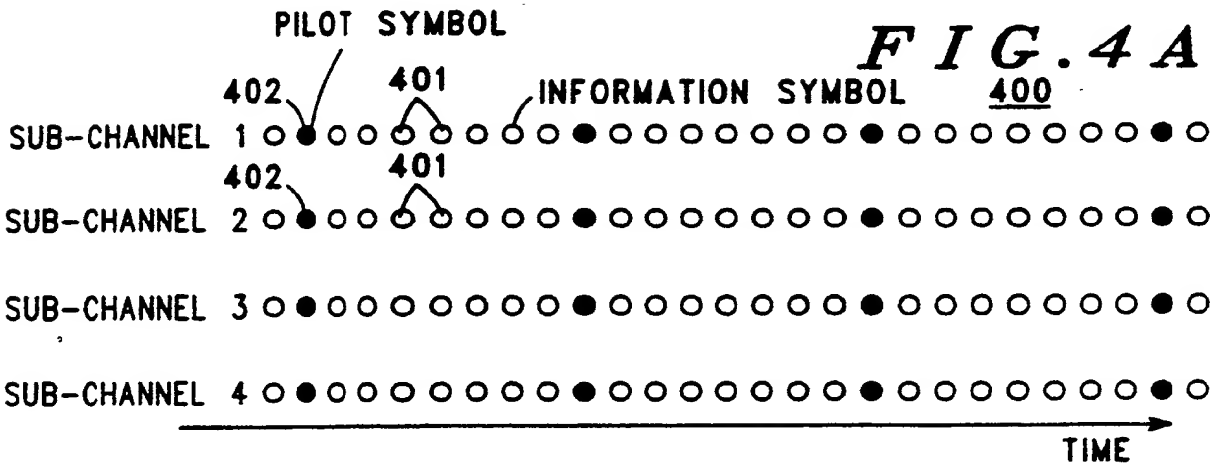

FIG. 4A

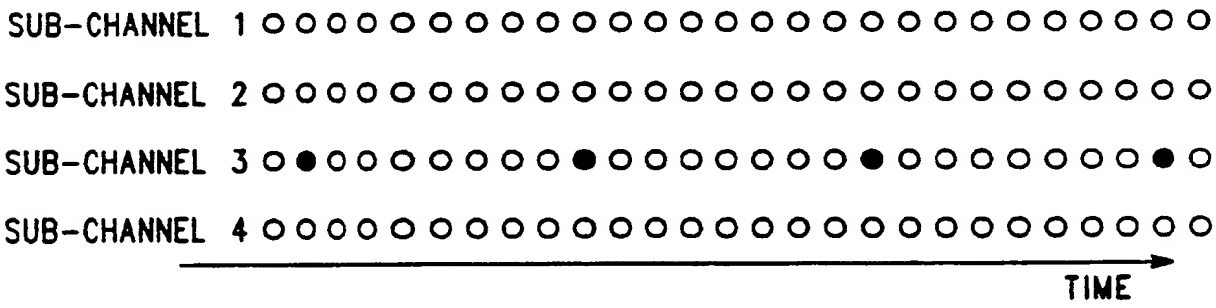

FIG. 4B

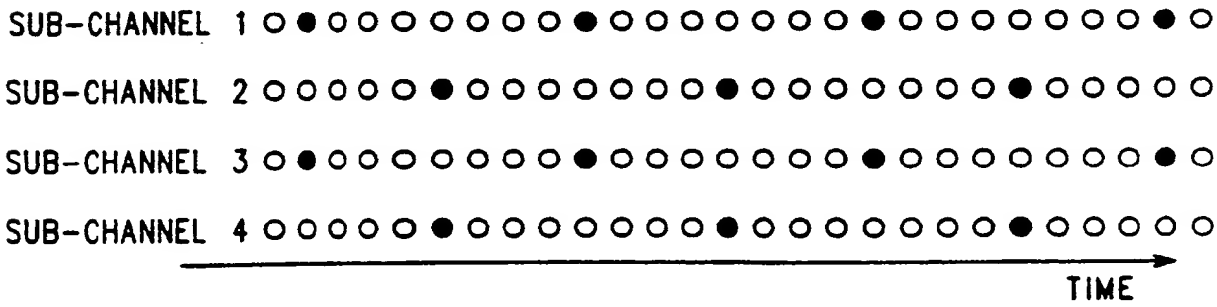

FIG. 4C

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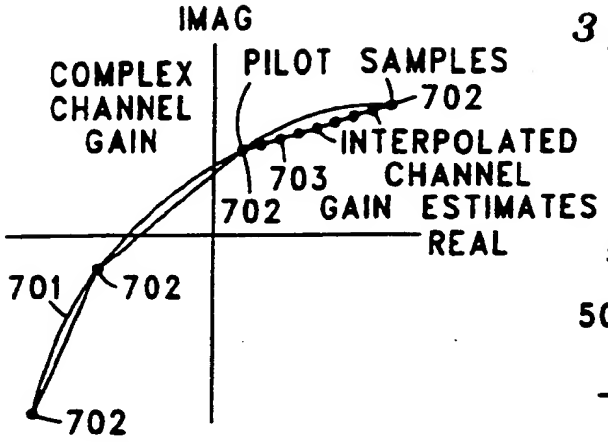


FIG.7

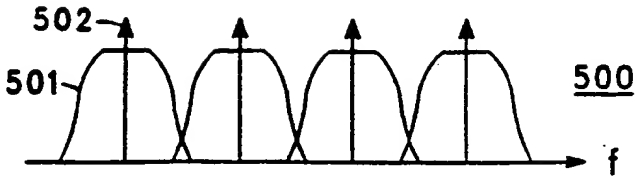
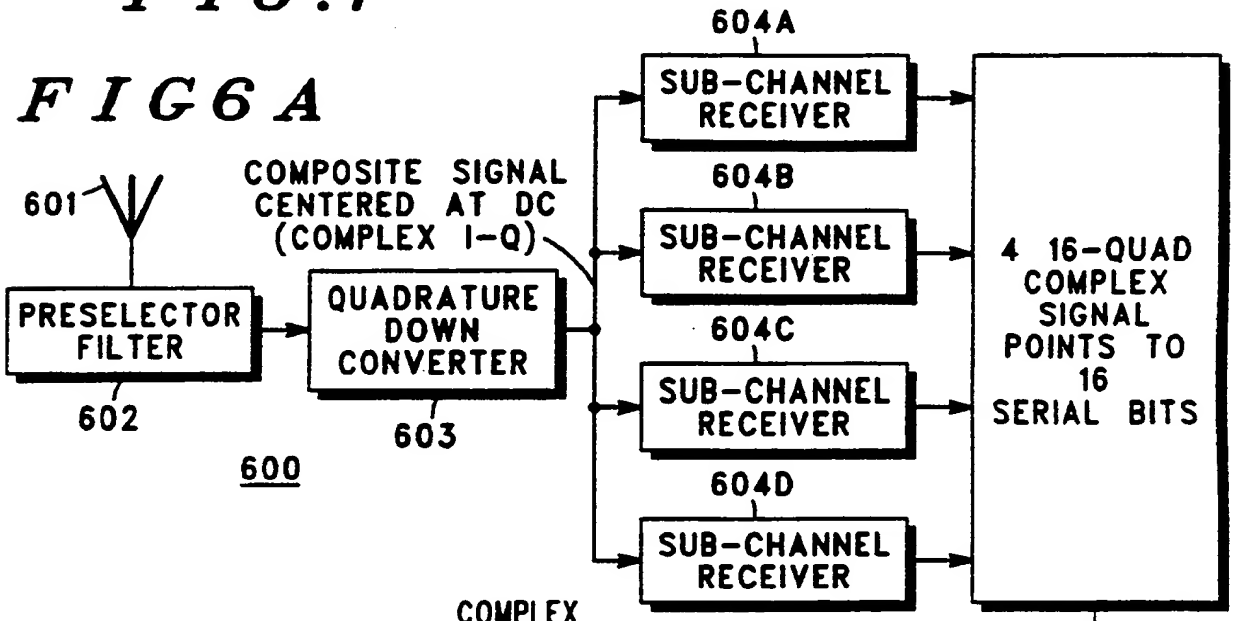


FIG.5

FIG6A



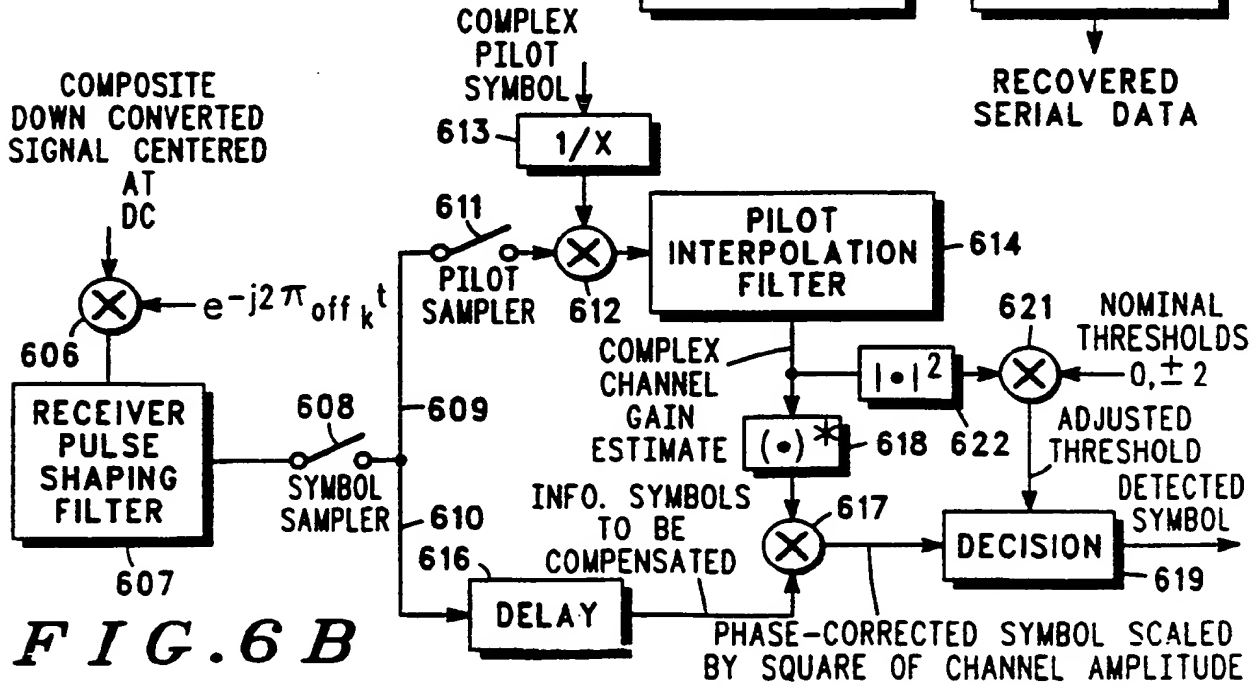


FIG.6B

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INTERNATIONAL SEARCH REPORT

International Application No. PCT/US91/03481

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC(5): H04B 7/02 H04L 1/02
US CL.: 375/40

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
US	375/40,38,39; 455/52,59,228; 370/98

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
Y	US, A, 4,881,245 (WALKER et al.) 14 November 1989 See figures 3 and 5.	1-6
Y	US, A, 4,581,748 (SASAKI et al.) 08 April 1986 See figure 1.	1,5,6

* Special categories of cited documents: [10]

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IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
24 January 1991	13 AUG 1991
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